The psychophysical and heart rate relationship between treadmill and deep-water running

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The relationship between ratings of perceived exertion and heart rate attained during submaximal running tests on a treadmill and during deep-water running was investigated in 12 male subjects. Heart rate and rating of perceived exertion scores analysed by analysis of covariance tested the equality of adjusted means and parallelism of the slope of this relationship. No significant difference existed between the slopes of the regression equations established for treadmill running and deep-water running. A paired *t*-test performed across the adjusted group mean heart rates revealed a significant difference between the two conditions. While the slope of the heart rate to rating of perceived exertion regression equations remained similar, the mean heart rate was 17 beats per minute lower in the deep-water running condition than during the treadmill run.

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Integral to the rehabilitation of injured athletes, physiotherapists must maintain the injured athlete's cardiovascular fitness whilst optimising repair of the injured part. Such athletes are often faced with altering or discontinuing their regular training, resulting in the effects of detraining (McArdle et al 1986). Alternative training methods that do not aggravate the injury must be employed if the athlete is to avoid detraining and a loss of cardiovascular fitness.

Deep-water running (DWR) has become a popular way of maintaining the fitness of injured athletes participating in sports involving running. By running in an essentially weightless environment, through the use of a flotation device in deep water, the ground reaction force associated with foot strike during running gait is eliminated. By using DWR as opposed to other partial or non-weightbearing exercise such as cycling or swimming, the runner is able to achieve specificity of training by the use of muscle groups in a pattern that is specific to the athlete's running gait. If a normal running style and posture is maintained in water, then specific metabolic and neuromuscular training effects do occur in similar magnitude as they would in response to running on land (Hamer and Morton 1990).

The purpose of this study was to examine the relationship between HR and rating of perceived exertion (RPE) as measured by the Borg scale (Borg 1982) whilst running in deep water and compare this with the well documented relationship of heart rate (HR) and RPE when running is performed on a motor driven treadmill. The significance of the study lies in the need to accurately prescribe exercise intensity in order to achieve the appropriate training effects for DWR.

Heart rate response to immersion and exercise in water

The physiological responses of the body to water immersion are due to the physical differences between the media of air and water. The hydrostatic pressure exerted by water increases by 22.4 mmHg for each 0.305 metres of water depth (Greenleaf 1984). Immersion increases the external pressure on the lower body and this pressure opposes or compensates for the hydrostatic pressure inside the blood vessels of the lower body. Immersion to the neck level results in:

i) an increase in the mechanical pressure on connective tissue proportional to the depth of immersion; and
ii) compression of the abdominal contents forcing the diaphragm cephalad and compressing

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cardiorespiratory structures in the thorax (Greenleaf 1984).

During immersion with the head above water, increased pressure in the lower body regions causes a redistribution of blood from the periphery to the thorax (an increased venous return) thus distending the heart and vessels. This causes an increase of about 30 per cent in cardiac output via a 35 per cent increase in stroke volume, due to improved diastolic filling (Arborelius et al 1972). During immersion in water of temperature below thermoneutral (33-35 degrees C), venous return and hence stroke volume, will be affected by the combination of the increased pressure in the lower body regions and the water temperature (Avellini 1983).

Rennie et al (1971) studied the effects of water immersion to the neck level on the cardiac output, the HR and the stroke volume at rest and during exercise, focusing on the way temperature affects these variables. At rest, immersion in water of temperature less than 34 degrees C (thermoneutral) resulted in a 15 per cent increase in the arterio-venous oxygen difference (a-$\bar{v}O_2\Delta$) as compared with resting in air. As inspired air contains the same fraction of oxygen for subjects resting in air or in water, the cardiac output was assumed to have decreased and this was calculated to be a 12 per cent drop, principally accounted for by a 15-20 per cent decline in HR. The lower HR was reasoned to be due to cutaneous and limb vasoconstriction in response to cold stress. The study also showed that HR responses to light and moderate workloads in cold water remain lower than those HRs when the same exercise is performed in air. This is due to the cold stress and a negative feedback control that results in a higher stroke volume.

A decreased HR response to immersion in water was also shown by Johnson et al (1977) who measured oxygen consumption and HR responses at rest and during the performance of identical callisthenic type exercises. Johnson et al (1977) reported that HRs were depressed by 10-15 beats per minute after standing submerged to the shoulder level in water (26.5 degrres C) for 30-60 seconds. They proposed this to be partly due to a reflex response mediated via cold receptors in the skin and partly due to the effect of hydrostatic pressure exerted against the legs and torso.

Changes in HR may also be the result of exercise rhythm. Alterations in the entrainment of HR to exercise rhythm has been investigated by Paterson et al (1986). These authors evaluated HR and ventilatory responses during bicycle ergometry and arm cranking at constant workloads. Nineteen subjects, unfamiliar with the experimental tasks, performed four minutes of exercise at their preferred movement frequency followed by forced incremented and decremented rhythm changes each lasting three minutes. They reported that HRs associated with incremental frequency changes were significantly higher. These HRs decreased when the exercise rhythm was decremented to preferred movement frequencies. This would then indicate that speed of limb movement may also influence the HR response observed.

Measurement of perceived exertion

Ratings of perceived exertion (RPE) offer a method of subjectively measuring exercise intensity. It is well documented that levels of anxiety influence the levels of circulating catecholamines which therefore influence HR (Kaplan and Sadock 1988). This suggests that psychophysical responses influence exercise performance, with this being most evident during the initial stages of an exercise bout. Borg (1982) developed a category scale of perceived exertion, which increases linearly with exercise intensity, to quantify psychophysical responses to exercise. The scale ranges from six to 20 and was designed to approximately correspond to HRs ranging from 60 to 200 beats per minute. It has been shown that there is a strong linear relationship between HR and perceived exertion across several exercise intensities. Borg (cited in Mihevic 1981) originally reported a correlation of $r = 0.85$ between RPE values and the HR response to a bicycle ergometer task involving progressively increasing exercise intensities. Mihevic (1981) stated that these findings were consistent for male or female subjects, bicycle or treadmill exercise, progressively increasing or randomly ordered exercise intensities, continuous or intermittent exercise, and arm or leg exercise.

It must be noted that although HR measures physiological strain and is found to be linearly related to RPE, there is a relative independence between HR and RPE when examining the sensory cues used to determine RPE (Mihevic 1981). Factors such as ventilation, oxygen consumption ($\dot{V}O_2$), catecholamines, blood glucose and lactic acid combine to give an overall feeling of perceived exertion. The strong linear relationship between HR and RPE is almost inherent in the actual scale and does not provide evidence that people consciously monitored their HR as a psychophysical measure of exercise intensity (Mihevic 1981).

The use of perceived exertion in relation to water-running was studied by Bishop et al (1989). They investigated HR, $\dot{V}O_2$ and RPE relationships observed from seven trained runners during treadmill running and during DWR. Subjects ran for 45 minutes at a preferred running speed on both the treadmill and in the water to simulate the normal training conditions whereby running speed was self-selected. Water running was performed in deep water using a buoyant vest (Wet Vest Bioenergetics Inc.). Close supervision throughout the duration of the 45 minute test ensured the correct technique was maintained. Running speed was periodically varied by the subjects throughout the 45 minute period so that the run could be completed. Bishop et al (1989) concluded that absolute $\dot{V}O_2$ was 36 per cent higher during exercise on the treadmill than in water, despite the similar ratings of perceived exertion and HR values for the two modes of exercise. However, they did note that the non-significant difference between HRs should be interpreted with caution because of low statistical power of the HR analysis used in the study.

Problems with self-regulated water running programs have also been reported. Stephens (1981) reported that some athletes were training until they almost collapsed due to difficulty in gauging the intensity of water running they were performing. Anecdotal evidence from coaches has suggested that because there was no pounding on a solid surface, as would occur when performing track running, the runners did not get the aching heavy feeling that had been noted as a sign of fatigue, and could over-exert themselves in the water. These reports highlight the difficulties of subjectively setting the intensity of water running.

Method

Sample

The subjects were 12 volunteers from a population who responded to advertisements circulated amongst physiotherapy undergraduate students and members of a local surf club. The subjects were males aged between 18 and 30 years. Volunteers were excluded from the study if they had a known history contra-indicating moderate to intense physical exercise as assessed by the Physical Activity Readiness Questionnaire (PAR-Q) (American College of Sports Medicine, 1986). The mean (SD) age of the 12 subjects was 19.3 (1.4) years, their height was 180.7 (6.92) centimetres and the body mass of the subjects was 75.9 (9.9) kilograms. Subjects were required to complete the PAR-Q and sign an informed consent document prior to participation in the study. The study was approved by the Ethics and Human Rights Committee of Curtin University of Technology, Western Australia.

Research design

Each subject performed a series of six incremental submaximal work intensities both running in deep water, in which the subject was unable to make contact with the bottom of the pool, and running on a treadmill. The differing exercise conditions, that is, water versus treadmill, represented the independent variables. Heart rate and RPE represented the dependent variables in both exercise environments.

Familiarisation

Procedure for water running

All subjects were required to familiarise themselves with the technique of DWR on the same day as the testing. This involved application and removal of the flotation device and the Polar 4000 sports-tester (Polar Electro OY, Finland). With equipment in situ, the participant performed the technique of DWR, with repeated instruction and feedback. Once the correct style had been achieved (Hamer 1995, Lucas 1994) emphasising, for the legs, a reaching stride with an active pull through the water, and for the upper limbs, the use of lightly clenched fists, the subjects then practised keeping their own stride rate in time with the cadence provided by the metronome. This was done by initially running at the slowest cadence of 60 strides per minute until the correct style and cadence was achieved and then gradually increasing speed until the fastest cadence, 80 strides per minute, was achieved. Subjects were reminded that each of the six set cadences were to be maintained for four minutes and again, close attention to technique was emphasised during this cadence familiarisation period.

Procedure for treadmill running

The subjects received instructions and demonstration concerning mounting the treadmill at speed and beginning the timer on the sports-tester monitor once mounted. Each subject was familiarised at the slowest speed progressing through to the fastest speed. A trial of mounting the treadmill at the fastest speed ($12km.hr^{-1}$) was then undertaken.

Other reliability/validity factors

1) Concomitant recording by an electrocardiograph and the Polar 4000 sports tester (Polar Electro OY, Finland) ensured validity and reliability in the determination of HR during the treadmill test.
2) An explanation was given as to the significance of the use of the RPE card to measure a rating of perceived exertion following each exercise intensity level. It was explained that a value between 6 and 20 must be recorded at the completion of each work level, to give a subjective level of perceived exertion, with 6 being very, very light exercise and with 20 perceived as very, very hard. It was emphasised that the RPE was to reflect a total body score rather than fatigue in any specific limb or muscle group.
3) Walk recovery was encouraged between work periods and following the familiarisation process. This was important in the higher work levels when exercise intensity was likely to exceed 50-60 per cent of predicted maximal oxygen consumption and had the potential to result in progressive lactate accumulation which may be reflected as higher RPE responses.
4) At least 15 minutes recovery time was allowed following the familiarisation process and eight minutes of recovery time allowed in between work periods.
5) The performance of the tests in the pool and on the treadmill were on successive weekends and at the same time of the day to take in to account the natural circadian rhythms of the subjects. However, random presentation of pool/ treadmill was not possible due to practical time constraints with the use of the pool.

Administration of the tests

The water running test

All testing of DWR was performed in the diving pool at Beatty Park Aquatic Centre, Perth, where the temperature of the water was maintained at a constant 27 degrees C. On the day of testing, each subject was required to perform the mandatory familiarisation

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session as previously outlined. This was followed by a recovery period of 15 minutes, during which the subject was encouraged to leave the pool and partake in a walk recovery. Each subject was then prepared for testing by application of the Polar 4000 sports-tester (Polar Electro OY, Finland) and the flotation device. This device comprised two rectangular foam rubber floats each of the following dimensions: length = 217mm; breadth = 171mm; width = 76mm. Comfort and a snug fit were the important criteria in fitting the floats. The anterior float was placed over the anterior aspect of the sternum and the posterior float over the spinous processes of approximately T3 through to T11. The two floats were held snugly to the chest wall by durable webbing joined with easily detachable clips. It was important that the floats were not so tight as to restrict expansion of the chest wall during the test. Also, a free motion of the arms through the water was important, hence alignment of the floats in the midline of the body was essential.

Before entering the water, the HR of the subject was recorded to ensure that it had returned to within five beats per minute of that value recorded as resting level before the familiarisation process. Upon entering the water, all equipment was checked and adjusted as necessary, and the commencement of the metronome beat signalled the beginning of the four minute test interval as timed by the sports-tester monitor. The monitor was set to record the HR at 15s intervals throughout the four minute run.

Throughout the four minutes of DWR, one of the investigators gave feedback, as necessary, to ensure the correct technique was being maintained. This concentrated on hip and knee flexion, then knee extension followed by extension of the whole limb. These movements were reinforced with the instructions "lift the knee forward, straighten the leg and pull the foot through the water as if trying to claw the bottom of the pool." The subjects were instructed to maintain lightly clenched fists, to prevent any sculling motions of the hand and to maintain a reciprocal arm action.

At the completion of the four minute work interval, each subject rated their perceived exertion level, left the water, removed the sports-tester and flotation device, towelled down and was encouraged to undertake the walk recovery. The values for HR were recalled from the sports-tester monitor and recorded. This was repeated at six different work intensities. The protocol used for incremental work rates is presented in Table 1.

Table 1. Protocol for increasing the cadence for each change in work level during the deep-water running test.

WORK LEVEL	CADENCE
1	60
2	64
3	68
4	72
5	76
6	80

Table 2. Protocol for increasing the work rate during the treadmill running test.

WORK LEVEL	TREADMILL SPEED
1	7 $km.hr^{-1}$
2	8 $km.hr^{-1}$
3	9$km.hr^{-1}$
4	10 $km.hr^{-1}$
5	11 $km.hr^{-1}$
6	12 $km.hr^{-1}$

Table 3. The results of the two-tailed paired *t*-tests comparing cadences measured at the treadmill velocities with the cadences set for the work rates of the deep-water running test.

DWR	Treadmill ($km.hr^{-1}$)	*t*	*df*	*p*
60	7	-4.53	11	<0.001
64	8	-6.51	11	<0.001
68	9	-6.74	11	<0.001
72	10	-4.97	11	<0.001
76	11	-1.97	11	0.075
80	12	-0.49	11	0.632

Cadence

Cadence was adjusted using the beat of a metronome pre-recorded onto a cassette tape. Each work level was four minutes in duration with an eight minute walk recovery in between.

The specific cadences were determined by a pilot study that was carried out prior to testing whereby three subjects were run at speeds on the treadmill varying from 6$km.hr^{-1}$ to 13 $km.hr^{-1}$ and cadences (alternate footstrikes per minute) were recorded. The same three subjects were then run in the pool to:

a) investigate the viability of running through water at those cadences already achieved on the treadmill, and
b) determine the maximum cadence that could be achieved in the water whilst maintaining correct technique.

Results indicated that for the age and

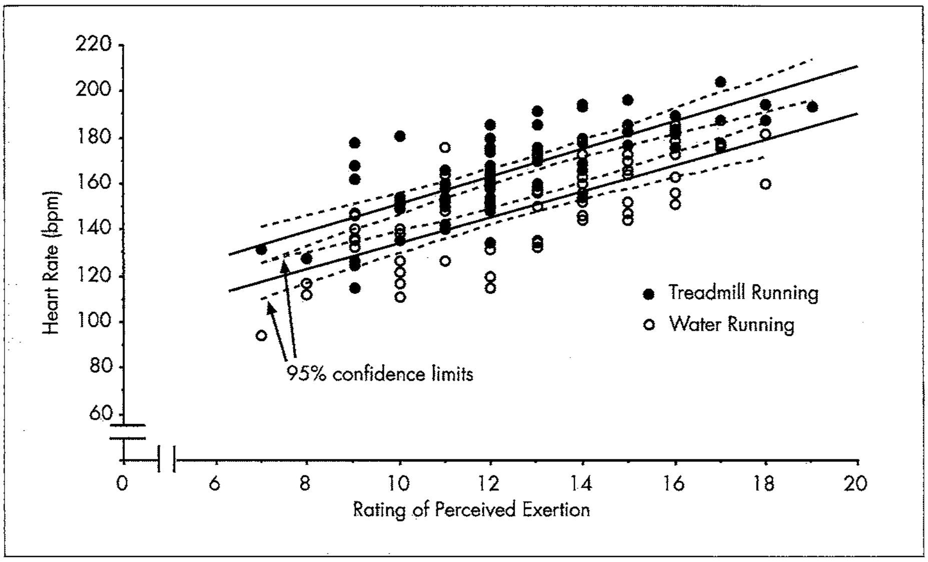

Figure 1. Graphical representation of the relationship (±95% confidence limits of the mean) between heart rate and rating of perceived exertion during deep-water running and treadmill running.

ability of the population, cadences from 60 strides per minute through to 80 strides per minute would be appropriate to elicit the desired HR responses and would be achievable in terms of moving the lower limbs through the water at high speed and overcoming large resistive turbulent forces whilst maintaining a mechanically correct DWR technique.

Cadence takes on the role of one of the independent variables in this study. In essence, cadence has been controlled for in both work environments. Cadence has been controlled during DWR as subjects were required to mimic the beat of the metronome in running at a particular stride frequency. Cadence is also controlled on the treadmill as the speeds selected, that is, 7-12km.hr^{-1}, roughly corresponded to those fixed cadences chosen in the water when investigated in the pilot study. Whilst running on the treadmill, the purpose of recording each subject's cadence in the last minute of each work period was to examine whether or not a similar cadence was being achieved on the treadmill as was being controlled for in the water at each work intensity level.

The treadmill test

All treadmill running tests were performed in the Exercise Science Laboratory at the Curtin School of Physiotherapy, on the weekend following the DWR tests. All subjects were required to undergo a familiarisation procedure for treadmill running. This was followed by a 15 minute walk recovery. Each subject was then prepared for testing with the application of the sports-tester in the same manner as used in the preparation for water running.

The subject ran for four minutes and in the last 30 seconds of the run, the number of footstrikes for a specified leg was counted by one of the investigators giving a value for cadence in cycles per minute. At the completion of the four minute test the subject performed an eight minute walk recovery. The next four minute work period was then performed with the increase in work rate following the protocol as outlined in Table 2.

Parameters measured

Heart rate was measured using a Polar 4000 Sports Tester (Polar Electro OY, Finland). The sensor/transmitter component was fitted just below the pectoral muscles, with the positive electrode aligned with the mid clavicular line on the subject's left thorax at the level of the fifth intercostal space. The monitor was worn on the subject's wrist throughout the treadmill tests. To avoid the monitor being submerged during the water running tests it was fastened onto a cloth headband. The monitor was set to record HR every 15 seconds. For both the DWR test and the treadmill test, an average of the last four HRs for each work level was calculated, to establish the steady state HR for that energy expenditure level.

The level of perceived exertion was determined at the conclusion of each work level of the DWR test and the treadmill test. The Borg scale (Borg 1982) was used to measure this variable. The Borg RPE scale was presented on a large piece of cardboard with a brief description of the subjective feelings relating to every second number. This was shown to each subject prior to each of the tests and each was instructed to choose a number at the end of each work level that corresponded to their overall feeling of perceived exertion.

Cadence was measured on the treadmill by counting the number of times one foot struck the treadmill belt in the last 30 seconds of each work period. This number was then multiplied by two to give a value for cadence in footstrikes per minute which represented the number of times one foot, be it the left or the right, struck the moving treadmill belt in the last minute of the work period.

Statistical analysis

Statistical treatment of the data was performed across the six incremental exercise intensities evaluated, with the results for the 12 subjects who took part in the investigation grouped together to allow comparison to be made across the two different exercise conditions. Heart rate and RPE data collected during DWR and treadmill running were plotted against each other and regression equations and the Pearson product moment correlation

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coefficients were calculated for each of the exercise conditions. Paired two-tailed student t-tests were performed comparing cadences across the two different environments. A one-way analysis of covariance (BMDP1V-One-Way Analysis of Covariance) was performed across the six different exercise intensities between the two environments using the BMDP statistical package on the VAX mainframe at Curtin University of Technology. This analysis specifically addressed the regression equations and any difference between the adjusted mean HRs between the two environments. The adjusted mean HRs were calculated after determining that the slope of the regression line predicting HR from the RPE was not significantly different between the two conditions. The tests for the equality of adjusted means and zero slopes is based on the assumption that the slopes of the dependent variable on the independent variable are the same in each group and are invalid if the test for equality of slopes is significant at the $\alpha = 0.05$ level. Statistical inferences are drawn with respect to the adjusted group means (Roscoe, 1975).

Results

The Pearson product moment correlation coefficients for HR versus RPE were calculated to be $r = 0.75$ (HR = 6.01 x RPE + 91.25) for treadmill running and 0.72 (HR = 5.58 x RPE + 78.90) for water running. The scattergram and a depiction of simple linear regressions (± 95 per cent confidence limits of the mean for the HR versus RPE relationships for the treadmill and water conditions are presented in Figure 1.

Results for the comparison of cadences across the two conditions indicated a significant difference between cadences in the water and those measured on the treadmill in the first four work levels but not at the higher cadences (Table 3).

The one-way analysis of covariance performed across the six different exercise intensities between the two environments established that there was no significant difference in the slope or intercept of the regression equations established for treadmill and DWR ($F_{(1,140)} = 0.22, p > 0.05$). A two-tailed t-test performed across the adjusted group means revealed a significant difference ($t_{(141)} = 7.68$, $p < 0.05$) between the adjusted mean HRs between the two conditions. Specifically, the mean difference between the HRs across the submaximal RPE scores from 7-19 was 17 beats per minute lower in the DWR condition than during the treadmill run. The parallelism of the relationship and the difference between the HRs attained in each of the environments is clearly shown in Figure 1.

Discussion

The results from this investigation have important implications for the prescription of exercise intensities for DWR. In the past, prescription of exercise intensities for use during deep water-running, from the RPE:HR relationships for land and/or treadmill running, have been fraught with inconsistencies and deemed a precarious practice (Wilder et al 1993). However, in the present study, using the cadences and technique specified, a linear relationship between HR and RPE in the two different exercise environments (ie treadmill and DWR) has been established, thus allowing confident prescription of exercise intensity for DWR .

This study has shown that there is no significant difference between the slopes of the regression lines for the HR:RPE relationship for treadmill and DWR. Thus the increase in HR as RPE increases during submaximal work rates is at the same rate for DWR as for treadmill running. However, the mean HRs for the same RPE do differ for treadmill running as compared with those attained during DWR. The HR values for DWR are significantly lower than for treadmill running across the submaximal RPE range (7-19). This decrease in HR whilst immersed up to the neck, in a water temperature less than thermoneutral, is predominantly caused by the increased hydrostatic pressure exerted against the upright body (Arborelius et al 1972) concomitant with an induced bradycardia as a reflex response to stimulation of cold receptors in the skin (Johnson et al 1977). This can account for a 30 per cent increase in cardiac output via a 35 per cent increase in stroke volume. The hydrostatic pressure of the water shunts blood from the periphery to the thorax thus increasing venous return and diastolic filling, with a concomitant increase in stroke volume. This effect provides a volume loading on the heart which is a desirable outcome for aerobic training programs (McArdle et al 1989). When submaximal work rates are similar (ie equivalent RPE) the same cardiac output is able to be achieved at a lower HR (Arborelius et al 1972).

Conclusions

The results and observations made during this study have important implications for the prescription of the intensity of DWR for young (18-30 year old) male subjects. The parallelism of the two regression lines for DWR and treadmill running allow a clear comparison of mean HR values through the submaximal RPE range (7-19). Running in deep water at the same RPE as when running on a motor driven treadmill can be achieved with a HR that is on average 17 beats lower.

Hence, when describing the intensity of DWR for this subject population, using the cadences and technique as specified, the target HR determined from treadmill running needs to be set lower by 17 beats per minute. Conversely, if the intensity is set according to RPE then the resultant HR can be expected to be, on average, 17 beats lower than that associated with submaximal running on a treadmill. This ability to work at a lower HR for the same submaximal work rate may indicate a greater efficiency of the cardiovascular unit due to an increase in stroke volume for the same cardiac output and is seen as a positive effect during both aerobic training and as the result of an aerobic training program.

The guidelines for the prescription of DWR using either HR or RPE established by this investigation will help to avoid the potential for the athlete to over exercise when performing DWR. Education of the athlete as to the expected average drop in HR across exercise intensities and the reasons as to why this occurs will be an important role for those who prescribe DWR for their injured athletes.

Recommendations for further study

1) To extend the study to incorporate the measurement of $\dot{V}O_2$ and calculation of cardiac output into the testing procedure.
2) To investigate entrainment of physiological variables to limb velocities during DWR activities.
3) To investigate physiological variables in relation to RPE for water running in a variety of populations, to enable application of the results to the wider community.

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